The colliding-wind binary WR140:
the particle acceleration laboratory

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arXiv:astro-ph/0510540v1 18 Oct 2005

ABSTRACT

WR+O star binary systems exhibit synchrotron emission arising from relativistic electrons accelerated where the wind of the WR star and that of its massive binary companion collide - the wind-collision region (WCR). These "colliding-wind" binaries (CWB), provide an excellent laboratory for the study of particle acceleration, with the same physical processes as observed in SNRs, but at much higher mass, photon and magnetic energy densities. WR140 is the best studied CWB, and high resolution radio observations permit a determination of several system parameters, particularly orbit inclination and distance, that are essential constraints for newly developed models of CWBs. We show a model fit to the radio data at orbital phase 0.9, and show how these models may be used to predict the high energy emission from WR140.

Key words: stars:individual:WR140 – stars:Wolf-Rayet – radio continuum:stars

1 INTRODUCTION

The 7.9-year period WR+O system WR 140 is the archetype CWB. It exhibits dramatic variations in its emission from near-IR to radio wavelengths (Williams et al. 1990; White & Becker 1995), and at X-ray energies (Pollock et al. 2005), that are modulated by the highly eccentric orbit ($e \approx 0.88$), with the stellar separation varying between 2 and 30 AU. The variations in the synchrotron emission could arise due to a number of mechanisms. The most widely discussed possibility is changing free-free opacity along the line-of-sight through the stellar wind envelopes to the WCR as the orbit progresses. However, large changes in the stellar separation (D) in an orbit like WR140 alters the intrinsic synchrotron luminosity of the WCR ($\propto D^{-1/2}$) and the free-free and synchrotron absorption within the WCR. The Razin effect and Coulomb cooling all increase with decreasing D. Inverse-Compton (IC) cooling of the shocked gas is also important, particularly at higher frequencies, varying strongly with separation. All of these processes are included in recently developed models of CWBs that are based on 2-D hydrodynamical models to describe both the stellar winds and the WCR, giving a more accurate representation of the spatial distribution of the thermal and non-thermal emission (Dougherty et al. 2003; Pittard et al. 2005).
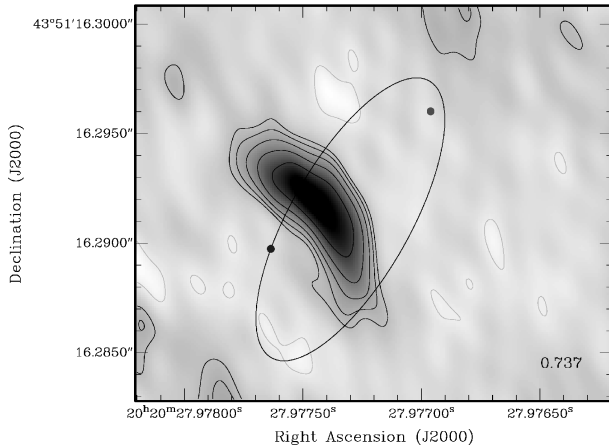
2 OBSERVATIONS

In addition to new models, recent observations have been obtained with the VLA and the VLBA that give new con-

straints to models of WR140. A 24-epoch campaign of VLBA observations of WR140 was carried out between orbital phase 0.7 and 0.9. An arc of emission is observed, resembling the bow-shaped morphology expected for the WCR (Fig. 1). This arc rotates from "pointing" NW to W as the orbit progresses which, in conjunction with the observed separation and position angle of the two stellar components at orbital phase 0.3 (Monnier et al. 2004), leads to solutions for the orbit inclination of $122 \pm 5°$, the longitude for the ascending node of $353 \pm 3°$, and the orbit semi-major axis of 9.0 ± 0.5 mas. From the $a \sin i$ derived by Marchenko et al. (2003), we can derive a distance of 1.85 ± 0.16 kpc to WR 140. This represents the first distance derived for CWB systems *independent* of stellar parameters, and together with the optical luminosity of the system implies the O star is a supergiant. In addition, total flux measurements from the VLA (Fig. 2) show that the radio variations from WR 140 are very closely the same from one orbit to the next, pointing strongly toward emission, absorption and cooling mechanisms that are controlled largely by the orbital motion (Dougherty et al. 2005).

3 MODELLING THE RADIO EMISSION

Using these new system parameters, we have applied newly developed radiative transfer models of CWBs to the spectrum of WR 140 in order to investigate the emission and absorption processes that govern the radio variations. At orbital phase 0.9, an excellent fit to the spectrum is possible (Fig. 3). The free-free flux is negligible compared to the

Figure 1. An 8.4 GHz VLBA observation of WR 140 at orbital phase 0.737, with the deduced orbit superimposed. The WR star is to the NW.
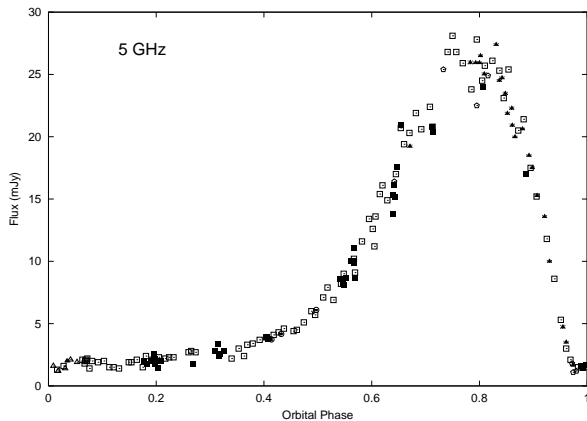

Figure 2. 5 GHz VLA observations of WR 140 as a function of orbital phase from orbit cycles between 1978-1985 (pentagons), 1985-1993 (squares), 1993-2001 (triangles), and the current cycle 2000-2007 (circles). Open symbols are from the VLA, and solid symbols from the WSRT.

synchrotron flux, which suffers a large amount of free-free absorption by the unshocked O-star wind, as anticipated at this orbital phase since the bulk of the WCR is 'hidden' behind the photospheric radius of the O-star wind. The low frequency turnover in this model is due to the Razin effect. Similar fits can be determined for the spectrum at phase 0.8. However, we have difficulty at earlier orbital phases (~ 0.4) if the low frequency turnover is the result of the Razin effect, largely due to the low value of magnetic field strength that is required, and the commensurate extremely high acceleration efficiency that is implied. We are continuing to investigate this issue.

4   FUTURE DIRECTIONS

Our models of the radio emission provide both the spatial distribution and population of non-thermal electrons. From these, a robust estimate of the high energy emission
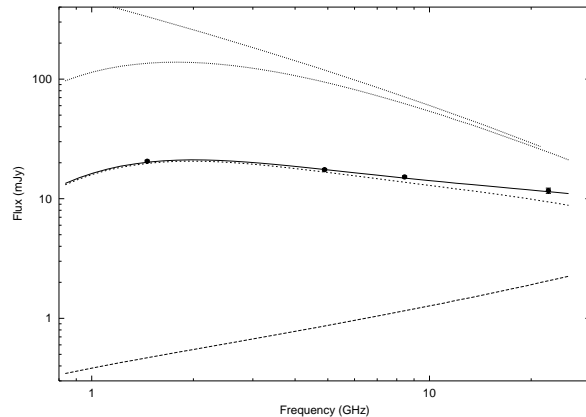
Figure 3. The spectrum of WR140 at orbital phase 0.9, fitted with a model with a wind-momentum ratio of 0.11. The observations are the solid circles. Various emission components from the model are shown - free-free (long-dashed), synchrotron flux (short-dashed), intrinsic synchrotron flux (dotted), and total flux (solid). The top curve shows the intrinsic synchrotron spectrum without Razin effect.

at X-ray and γ-ray energies is possible. This is of interest due to the potential association between WR140 and the EGRET source 3EG J2022+4317 (Romero, Benaglia & Torres, 1999), and is particularly relevant with several high energy satellites currently in orbit (Chandra, XMM-Newton, INTEGRAL) and further satellites and observatories which will be operational in the near future (GLAST and VERITAS). Previous work in this area has used the observed synchrotron luminosity and the equipartition magnetic field to estimate the IC luminosity (e.g. Benaglia & Romero 2003). However, a key consequence of our radio modelling is that we derive the intrinsic synchrotron luminosity, which is almost an order of magnitude different to the observed luminosity at phase 0.9 (Fig 3), and we determine the spatial distribution of the magnetic field. In a forthcoming paper, we explore the IC emission, relativistic bremsstrahlung, pion-decay processes and absorption due to pair-production in WR140, and the other well-studied CWBs WR146 and WR147 (Pittard & Dougherty, 2005).

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